Thermal Imaging Basics

To generate a thermal image, many individual thermopile pixels are arranged in a two-dimensional array. Starting with low resolution of 8x8 and 16x16 pixels, we also provide thermopile arrays with 32x32, 80x64 and 120x84 pixels. This allows our customers to generate thermal images with different spatial resolution for different applications. One of the main fields of interest of our customers include person detection in automation and security applications. Another area is hot spot detection, which includes a wide field of applications from engineering to fire suppression to industrial safety up to consumer goods.

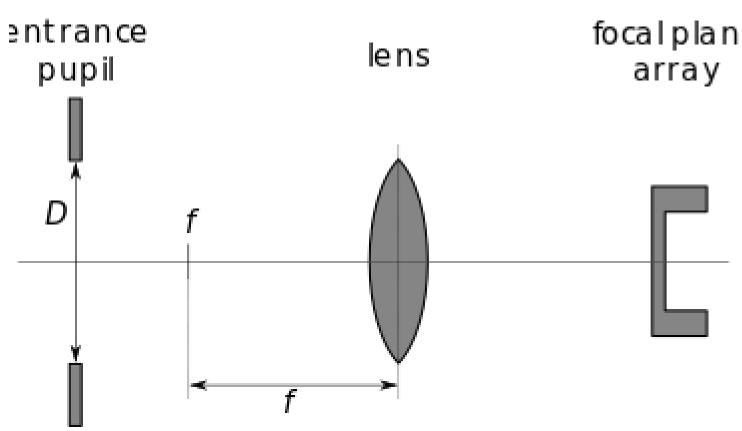
Although the basic principles of non-contact infrared temperature sensing and infrared thermal imaging are the same, we want to offer a few additional basics of thermal imaging as well. This includes a brief overview of the most important basics, which are essentially the same for infrared thermal imaging as for normal visible light cameras. In addition, we provide helpful hints about the most important characteristics that should be considered for spatial temperature measurements.

Infrared Optical Basics

An infrared (IR) optical system can be described by the same parameters that apply for the visible spectrum. The main difference apart from the wavelength, is the material of the lenses. For IR optics usually Germanium (Ge), Silicon (Si), Zinc Sulfide or Chalcogenide glass is used, since these materials show good transparency in the relevant IR spectrum, while ordinary glass is NOT transparent in the thermal infrared spectrum. The most common ones are Ge and Si, where Ge shows a better transparency but at a higher price. Special optical coatings can further improve the transparency, but of course this is also related to a higher price.

Relationship between f-number and Optical Performance

The two main parameters to describe the optical system are the focal length and the f-number. The focal length f in combination with the dimensions of the focal plane area (FPA) determines the field of view (FOV) of the camera. The f-number (N) is the ratio of the focal length to the lens aperture, essentially the diameter of the entrance pupil D. Since it is defined as N=f/D the f-number gets smaller the larger the entrance aperture gets.



In general, a smaller f-number corresponds to more radiation that can reach the sensitive matrix of the FPA. More radiation will result in a better signal to noise ratio (SNR). Because a low f-number requires a lens system with larger diameter, it also requires more material, and tighter manufacturing tolerances. Better performance is therefore only achievable at a higher price.

Furthermore, the f-number also has an influence on the dynamic range (temperature measurement range) of the optical system. The larger the aperture and the smaller the f-number, the more radiation will be detected by the IR sensitive pixel at a given object temperature. This will reduce the maximum temperature that can be detected, since the signal processing in our FPAs has a fixed gain which cannot be adjusted for different optics. For the analog-digital conversion this means that at a certain level of target radiation a maximum digital output value is produced. If the sensor receives a higher radiation due to smaller f-number, the output will still be the maximum digital value, so the measurement range is truncated, and the sensor is said to be saturated at those pixel locations.

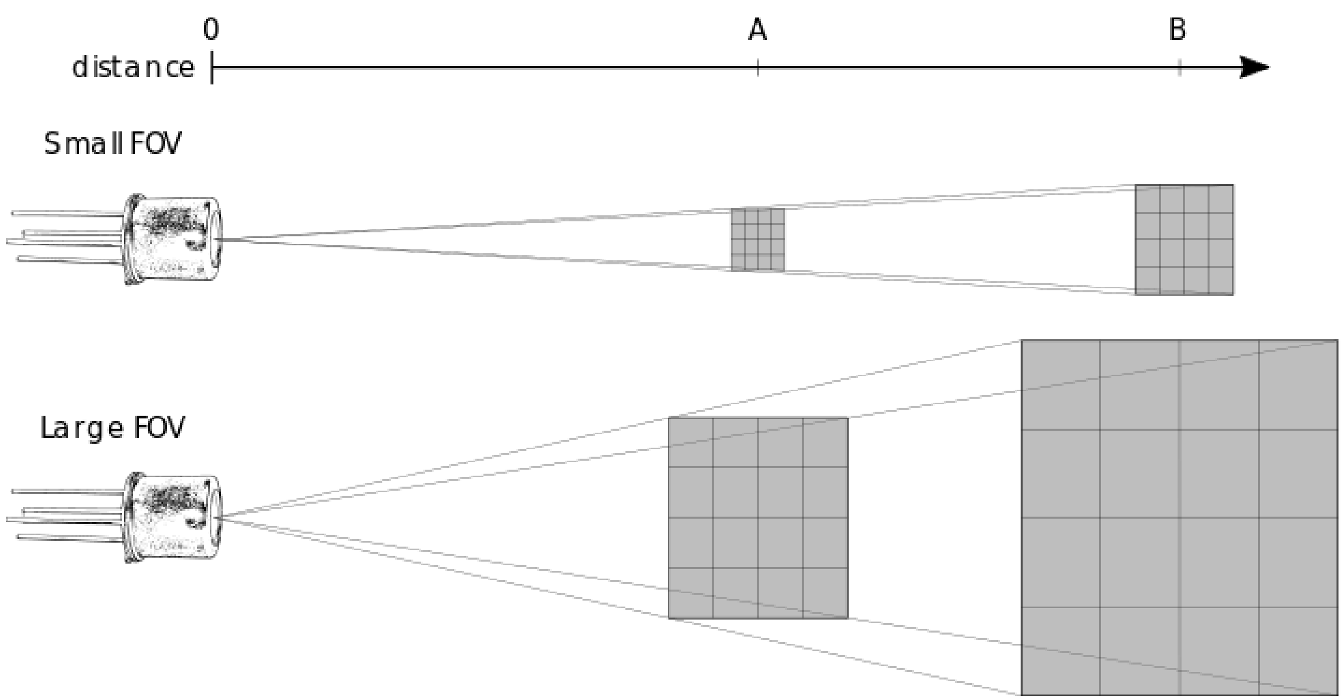
To expand the dynamic range without saturation, optical filters can be used to attenuate parts of the IR spectrum in order to reduce the amount of radiation at the sensor. The usage of small f-number and carefully selected optical filter allows good SNRs for lower object temperatures as well as increased measurement range.

Spatial Temperature Measurements

Before we look at temperature measurements we have to learn about the concept of spatial resolution of optical systems.

Spatial Resolution

If you want to take a thermal image of a scene or object, the three main parameters that determine the spatial resolution are the pixel pitch of the sensor array and the combination of FOV and distance between sensor and object. To get a better understanding of this relation, please refer to the following image:

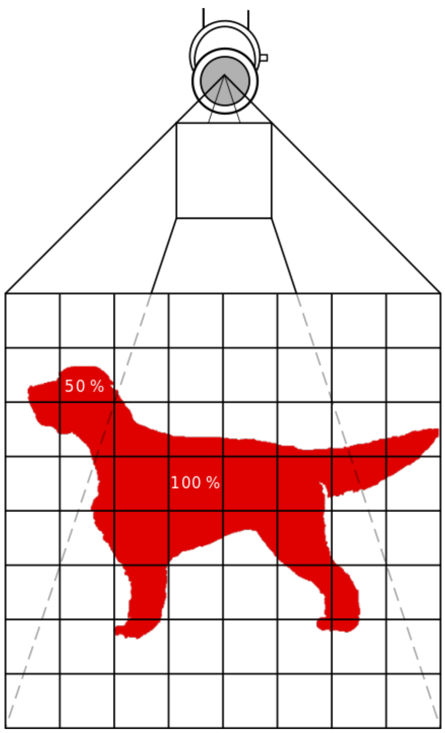


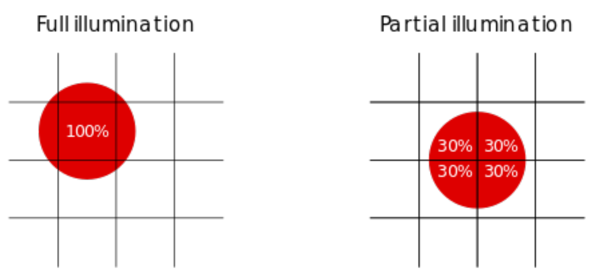
Imagine the FPA is projected through the lens optics onto a distant screen. The FOV determines the projected size of the FPA depending on the distance to the sensor. For the same distance (A resp. B) and same pixel pitch of the FPA a large FOV will result in a larger image with also larger individual pixels than a small FOV. So for greater distances the small FOV optics will have a higher spatial resolution, but of course they also show a smaller part of the scene. If you want to get the same spatial resolution with a large FOV you have two options. One is to reduce the measurement distance (from B to A). Another option is to increase the number of pixels. For the same FPA size this means reducing the pixel pitch. Please note that increasing the number of pixels and keeping the pixel pitch the same results in a larger FPA size which in turn gives a larger FOV.

Determine the Spatial Temperature

Regarding spatial temperature measurements the aforementioned relationships are important to keep in mind.

To determine the temperature of a specific feature or detail in your thermal image, this feature or detail has to illuminate at least one complete pixel. If this is not the case, the pixel will detect a mixed temperature of the object and the adjacent background. The following image will help to make things clear:





There are two pixels, where the filling factor of the dog versus the background is shown. For the 100% pixel in the middle the camera will detect the temperature of the specific part of the dog. But for the 50% filled pixel at the dogs head the camera will measure the superposition of the dog's head temperature and the background.

In example: If the dog's head temperature is 30°C and the background is 20°C, the camera will detect 25°C as the dog's head temperature.

This problem occurs especially for small objects and features. Even if the object is larger than one pixel the position of the object can have a strong influence on the temperature reading of the sensor. You can see this from the image on the right above.

A shift or movement of small objects can result in significant changes of the temperature readings and cannot be reliably detected. Thus, to determine the correct temperature of an object or feature more than one pixel should be illuminated by the smallest feature that should reliably be detected. It follows that for large target distances or small object sizes you should consider a smaller FOV or a sensor with more pixels.

How to Determine the FOV of your Camera

The ray law can be used to coarsely determine the FOV of the camera:

$$FOV = 2 \cdot \arctan\left(\frac{P \cdot n}{2 \cdot f}\right)$$

P equals the pixel pitch, n the number of elements in the corresponding direction. This means the FOV can vary in x- and y-direction if the number of elements is not equal in both directions.

To give an example: An 80x64 thermopile array has a pixel pitch of 90µm. Combined with a 17mm focal length optics the FOV will result in 24° x 20°:

$$FOV = 2 \cdot \arctan\left(\frac{90 \cdot 10^{-6}\ m \cdot 80}{2 \cdot 0.017\ m}\right) = 23.9°$$

Note, that this formula does not work well for wide FOV optics, since the aberrations of the system are not considered. To determine if an image is large enough for a filling factor of 100% the ray law can also be used. The image size I can be easily calculated by:

$$I = \left(\frac{O \cdot f}{d}\right)$$

where O is the object size, f the focal length and d the distance of the object. The image size divided by the pixel pitch results in the number of pixels illuminated. In example: A human with a shoulder width of 50 cm is 2 meters distant from an HTPA32x32 L5.0. Therefore, f = 0.005 m, O = 0.5m and d = 2m. This results in an image size of I = 1,25e-3 m. With a pixel pitch of 90 µm we get a total of 13.9 pixels illuminated.